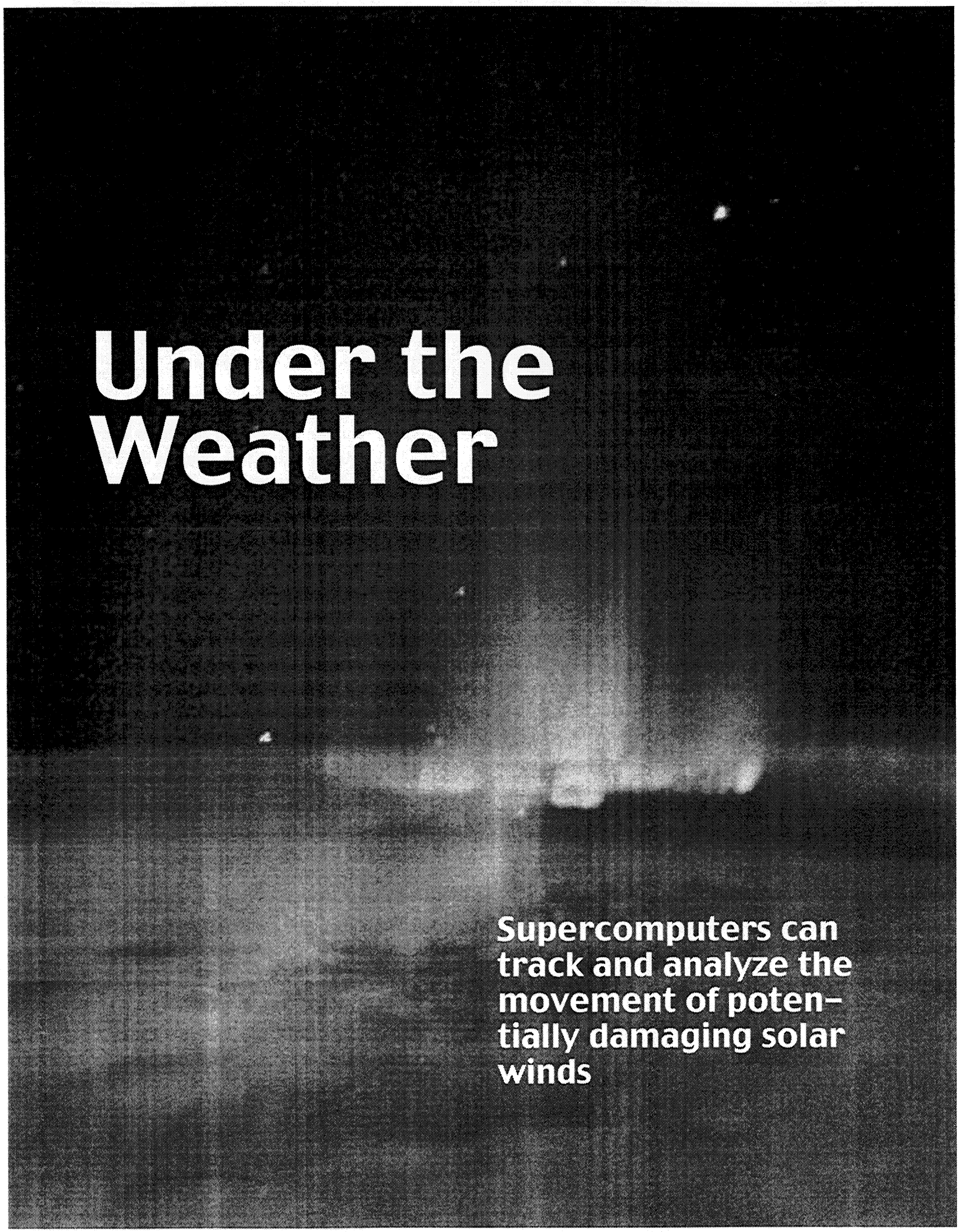
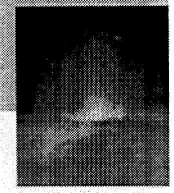


Under the Weather

Supercomputers can track and analyze the movement of potentially damaging solar winds



Normally, only people in the far north can enjoy the dancing beauty of the aurora borealis; however, an intense collision of charged solar particles with the Earth's magnetic field can magnify the Northern Lights so much that they are visible in the southern United States. Behind the light show lies enough flux of energetic particles carried by solar wind to render our planet uninhabitable. The Earth's magnetic field, also known as the *magnetosphere,* is the only thing that shields us from the Sun.

Even the magnetosphere cannot fully guard us from the wrath of the Sun. In March 1989, a powerful solar flare hit Earth with such energy that it burned out transformers in Quebec's electrical grid, plunging Quebec and the eastern United States into darkness for more than 9 hours.

Northern lights and energy grid overloads are not the only ways that a solar wind can affect us. A solar storm in July 1999 interrupted radio broadcasts. Solar activity can disorient radars and satellite sensors, break up cell phone connections, and threaten the safety of astronauts. A large bombardment of solar particles can even reduce the amount of ozone in the upper atmosphere. *Magnetohydrodynamics* (MHD), the study of magnetic fields in magnetized plasmas, can help scientists predict, and therefore prepare for, the harmful side effects of solar weather in the magnetosphere.

From the Sun to the Earth

Eruptions in the outer atmosphere of the Sun are the usual source of "space weather" phenomena. These eruptions, called *coronal mass ejections* (CMEs), are related to the changes in magnetic fields that the Sun produces. This activity is cyclical. Every 11 years, the frequency of eruptions spikes at what is known as a *solar maximum.*

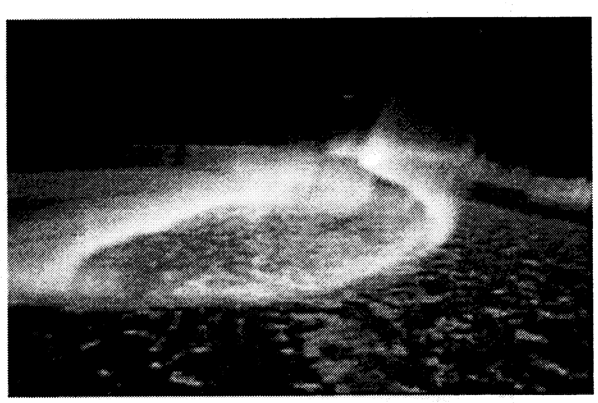
CMEs propel *plasmas,* or superheated ionized gases, into space through the background solar wind plasma. The solar wind plasma mostly consists of hydrogen atoms that have been fully ionized into protons and electrons. As the electrically charged particles move through space, they generate their own magnetic field. During a CME, the wind drags solar magnetic field lines into space to form the heliosphere. Because of the rotation of the Sun, the radially flowing solar wind produces spiral magnetic field lines known as the *Parker spiral.*

Rushing at speeds approaching 3 million miles per hour, a CME takes roughly 2 to 3 days to hit the Earth. The bombardment of Earth with solar protons is called a *solar proton event.* When the magnetic fields from the solar wind collide with the Earth's magnetosphere, the fields constantly twist and turn. Occasionally, they break apart and reform rapidly. This process of *magnetic reconnection* transfers large amounts of heat and energy from the solar wind to the magnetosphere.

Eye on the solar wind

For the past 35 years, the Space Environment Center in Boulder, Colorado, has been the United States' official space weather forecasting center. The organization collects images of the surface of the Sun, issues space weather advisory bulletins, and develops mathematical models for the activity of ions in outer space. The National Oceanic and Atmospheric Administration (NOAA) and the U.S. Air Force operate the Center jointly. Other major centers of space weather study in the United States include the NASA Goddard Space Flight Center and educational institutions such as UCLA, Dartmouth College, the University of Maryland at College Park, Rice University, and the University of Michigan.

The United States has also joined international efforts to study the Sun-Earth space environment. NASA, the European Space Agency (ESA), and Japan's Institute of Space and Astronautical Sciences (ISAS) formed the International Solar Terrestrial Physics (ISTP) project in the 1980s. The ISTP has launched several missions to study solar wind and its interaction with the Earth.



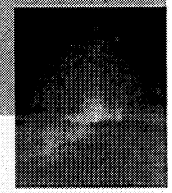
The aurora australis shines over the Southern Hemisphere.

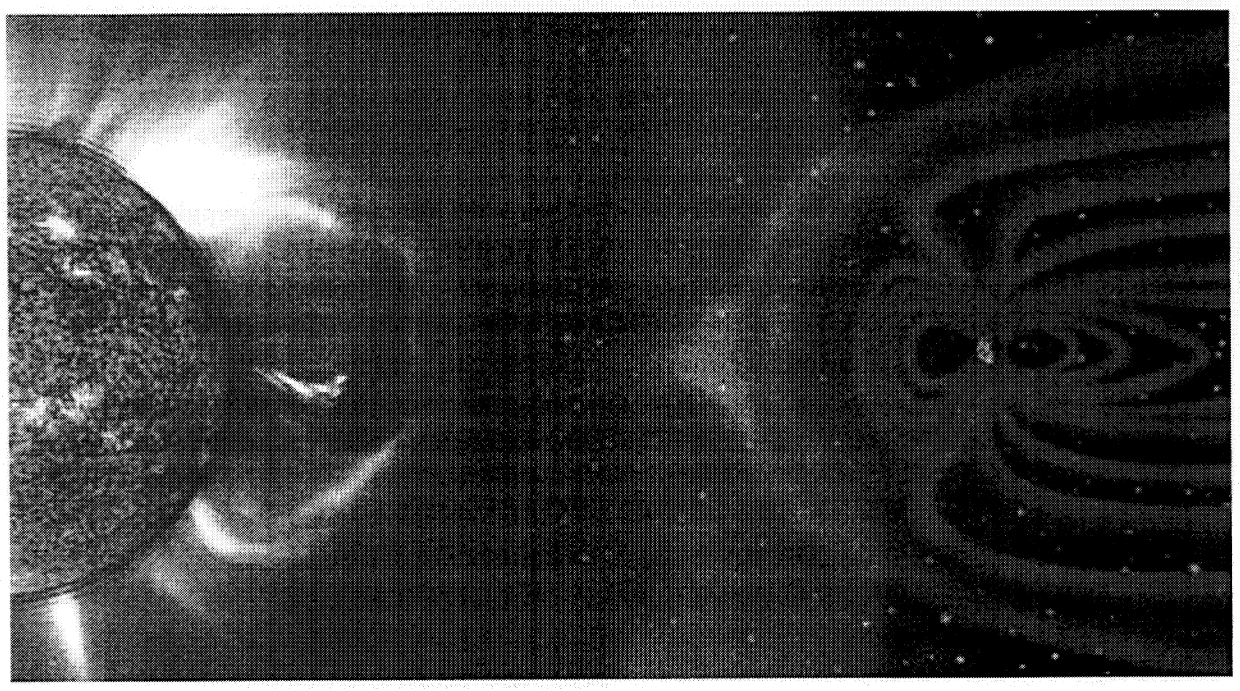
A number of satellites can detect disturbances on the Sun's surface up to 3 days before a CME hits the Earth:

- Both the Solar and Heliospheric Observatory (SOHO) and the Advanced Composition Explorer (ACE) satellites are positioned 1.5 million miles away, in an orbit that keeps them at a constant position between the Earth and the Sun.
- The ISAS launched the Yohkoh satellite in 1991. Yohkoh carries x-ray telescopes and other sensors that were contributed by the United States and Great Britain.

In addition, a large fleet of spacecraft measures the effects of the solar wind and CMEs on the magnetosphere:

- NASA's Imager for Magnetopause-to-Aurora Global Exploration (IMAGE), launched in 2000, is the first satellite dedicated to obtaining global images of the magnetosphere.
- The ISTP launched GEOTAIL to measure global energy flow and transformation in the magnetic field lines that spread out from Earth's





This illustration shows the Earth's magnetosphere deflecting a CME cloud. A CME takes 2 to 4 days to leave the Sun and reach Earth.
Image credit: The SOHO project

polar caps. Other ISTP spacecraft include WIND, POLAR, and Cluster II.

- The Los Alamos National Laboratory (LANL) created a series of satellites that analyze magnetospheric plasma and measure spaceborne electrons.
- NOAA and NASA developed the Geostationary Operational Environmental Satellites (GOES). Among the many instruments on GOES satellites are a magnetometer, an x-ray sensor, and other sensors that monitor the development of space weather.

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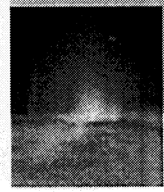


Research Profile: The Magnetic Field of the Heliosphere

Investigators:
Aaron Roberts and Melvyn Goldstein, NASA Goddard Space Flight Center, Interplanetary Physics Branch

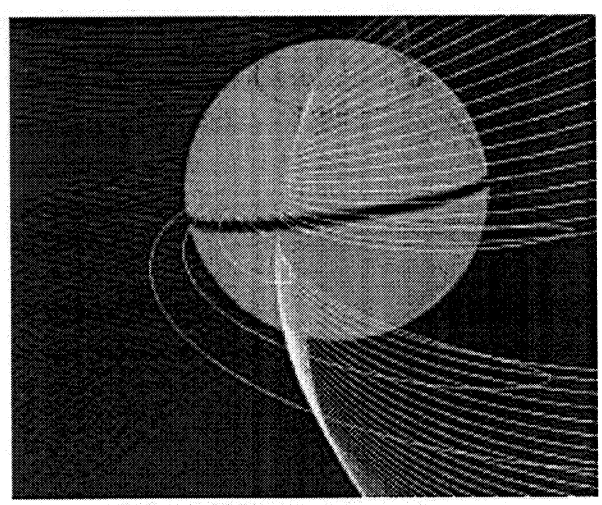
This research project simulated the dynamics of magnetic field lines and plasmas in the heliosphere to deepen our understanding of the approach of solar winds toward Earth. The study focused on various sources of field line distortions.

The researchers calculated solar wind conditions with a Flux-Corrected Transport MHD code. The code used a spherical-coordinate grid with general boundary conditions. A comparison with data from the Helios deep space probe showed that the code results were realistic.

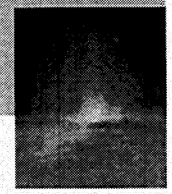
The simulations showed that the ideal Parker spiral field lines are easily modified, even in uniform flow conditions. In particular, the magnetic field deviates from the Parker spiral at a *sector boundary,* that is, the location near the ecliptic at which the field changes polarity. Here, loops of field form where the two polarities connect.

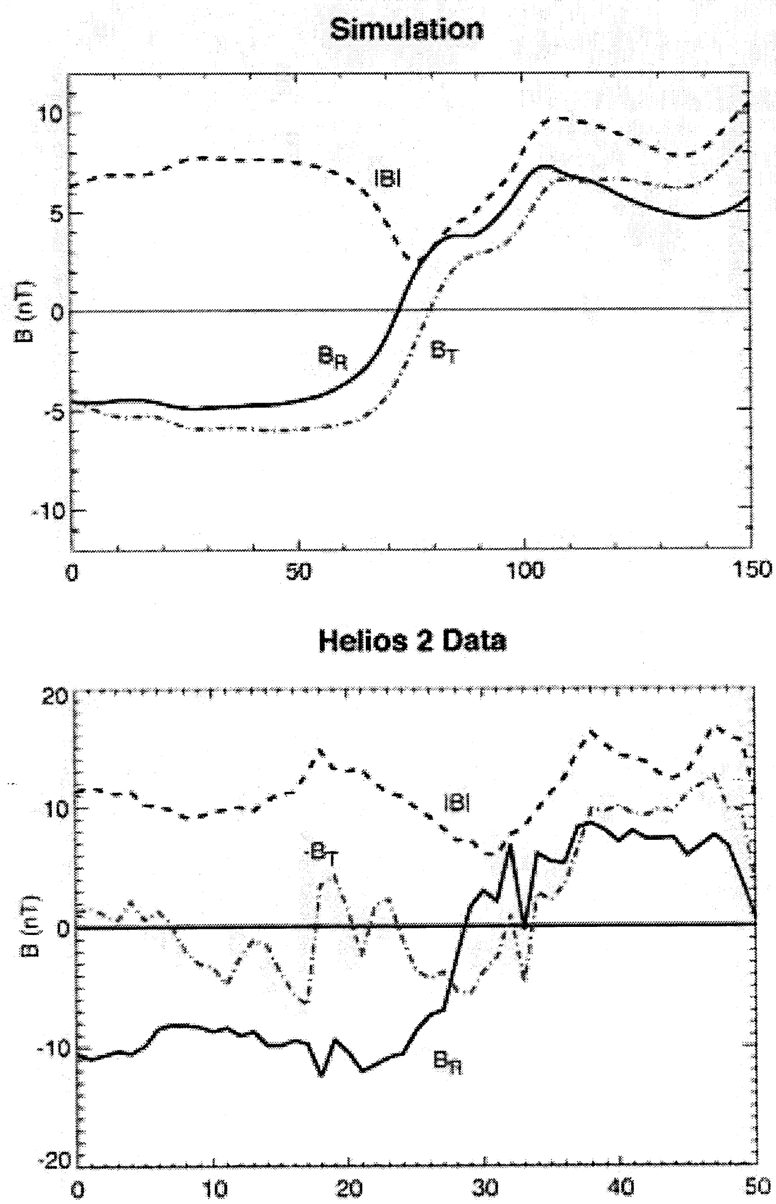
Another project simulated the presence of Alfvén waves in the heliosphere. An *Alfvén wave* is the movement of particles in a direction perpendicular to a magnetic field that bends the field lines. The simulation introduced Alfvén waves into a standard heliospheric flow, in which a high-speed solar wind surrounds a low-speed wind.

The results indicate that the simulations provide a valid description of the evolution of Alfvénic fluctuations in the solar wind. Therefore, scientists can use the simulation code to study realistic field configurations and their important effects on the propagation of potentially damaging energetic particles coming from the Sun. The investigators are currently optimizing the MHD code for a higher resolution and greater realism than before.



The yellow and red lines in this illustration represent simulated magnetic field lines from the Sun. The blue region on the green sphere indicates the sector boundary that separates magnetic polarities. *Image credit: Interplanetary Physics Branch, NASA Goddard Space Flight Center*





The top figure shows magnetic field values for the solar wind, calculated in this research project's simulation. For comparison, the bottom figure shows magnetic field recordings from the Helios 2 satellite, which was developed by NASA and the Federal Republic of Germany.